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Research Paper

Engineering Characterization of Local Limestone and Marlstone Aggregates in Koya Area as a Case Study

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There are huge limestones and marlstone outcrops surrounding the Haibat-Sultan Mountain in the Koya area. Knowledge of the physical, mechanical, and chemical properties of aggregates is important when using them in the construction industry. In this study, the usability of limestone and marlstone as sources of aggregate for construction purposes and different engineering applications was investigated. Results were carried out on the rocks limestone and marlstone from Fatha Formation in the Koya area as a case study. The engineering characteristics that have been mentioned in this study include: uniaxial compressive strength (UCS), Los Angeles abrasion value (LAAV), aggregate impact value (AIV), aggregate crushing value (ACV), dry density, porosity, water absorption and moisture content. The simple non-linear regression analysis has defined mutual relations between laboratory tests. The aggregate degradation properties of the aggregates showed strong correlations with the uniaxial compressive strength of limestone. The results indicated that it is possible to use this type of crushed limestone in concrete and road construction as a base course, while the marlstone aggregates are suitable for subbase courses in road constriction and non-structural concrete application.

1 Introduction

Aggregate construction material plays a vital role in the development of infrastructures in the world. The demand for aggregates reflects the development of construction in Iraq, especially in Kurdistan region. To surmount the demand, it was necessary to ensure rational exploitation of the aggregates available in the country by a valorization of these materials in the production of building construction. In order to resist crushing, deterioration, and disintegration from any relevant operations, including manufacturing, transportation, placement, and compaction, aggregates should be hard and durable enough to resist [1]. Aggregates are natural materials or non-natural ones depending upon the source from where these are extracted [2]. A major challenge for the aggregate and construction industries is finding alternative aggregate sources to overcome shortages.

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There are numerous publications dealing with existing or anticipated shortages of aggregates, particularly in developed cities. Between 70 and 80 per cent of the volume of concrete is occupied by aggregates. Aggregate is a major component in determining the properties of concrete, whether it is for structural or non-structural use. The most significant portion of the materials used in road construction is the aggregate. These aggregates are produced from rocks, created by the forces of nature by the cementation of minerals. On the other hand, the most significant portion of the materials used in road construction is the aggregate. Civil engineers and technologists must take the role of aggregates more seriously in terms of technological properties and economy since there are increasing demands of the construction sector.

Aggregate layer performance relies on the shape, grading, and composition of the particles and their physical, mechanical, and chemical properties [3]. Rock aggregates are the fundamental materials for most construction projects such as road, highway, railroad and building. Limestone aggregates constitute the most common sources of crushed rock aggregate and raw materials. Some studies have been confirmed that limestone aggregate has good efficiency for concrete and road works [4-6]. Marlstone is a type of sedimentary rock that can be used in the construction industry which includes cement manufacturing and construction aggregate. Marlstone is usually used as sub-grade layers or as a backfill for highway pavements in base and sub-base layers [7, 8].

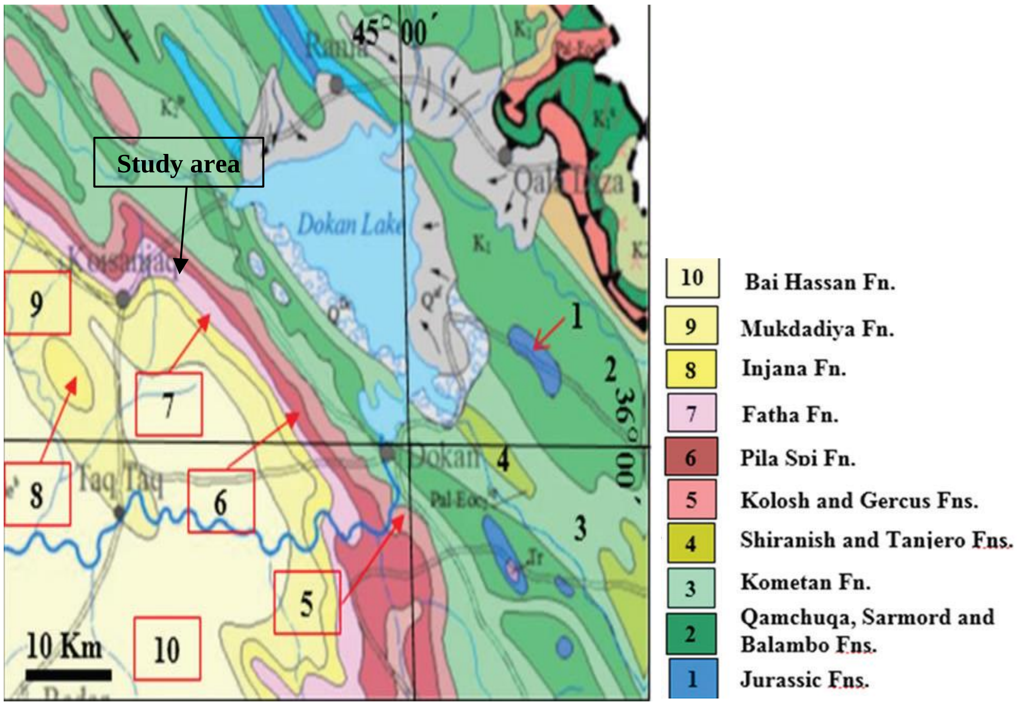

Fig. 1 – The geological map showing the location of the study samples [9].

Sedimentary rocks are the extremely valuable raw material used in a wide range of industries but the cement and construction industries are the main consumers. Sedimentary rocks make up a large proportion of the rocks found in the Kurdistan Region especially in Koya city. Some studies have investigated the possibility of using these rocks as a source of aggregate or fillers in the construction sector [10, 11]. Strategic evaluation of regional or local sedimentary rock resources needs to involve the physical, mechanical, chemical, and mineralogical properties of the stone. To ensure that construction aggregates are fit for purpose and meet the requirements of the end uses, it is important to have an understanding of the geology of the aggregate resources, physicomechanical and chemical properties of the studied aggregate. The most important parameters in any application and in their classification for different engineering purposes are the physio-mechanical properties of rocks used as aggregates [12].

In this study, several samples of limestones and marlstones were collected from five different locations in the Koya area to study some engineering properties for evaluating their suitability in the construction sector. The engineering properties that have been discussed in this study include: uniaxial compressive strength (UCS), Los Angeles abrasion value (LAAV), aggregate impact value (AIV), aggregate crushing value (ACV), dry density, porosity, water absorption and moisture content.

2 Materials and Methods

2.1 Geological setting of the study area of the aggregate resources

Most of the sedimentary rocks which are used for construction and industry materials in Iraq extracted from subsurface or surface outcrops widely exposed and huge deposits of high quality limestones and marls are found in Iraq especially in Kurdistan region, one of the main limestone and marlstone bearing unit is the Fatha Formation. The Fatha Formation is exposed as a continuous belt at the southwestern limb of Haibat Sultan Mountain. The formation consists of cyclic deposits of light grey marl, white to grey well bedded and hard limestone, reddish brown claystone and white massive gypsum. It is very widely exposed in the Low Folded Zone and Al-Jazira plain and furthermore in the Mesopotamian plain [9]. This research reviews the limestone and marl aggregates resources obtained from the Fatha Formation in the Koya area with regard to the engineering properties of these rocks for particular reference to construction manufacturing. The locations of studied samples are bounded by Universal Transverse Mercator (UTM) grid 3995000 and 3996000 North, 468000 and 470000 East. As shown in (Fig.1, Fig.2).

Fig. 2 – Side view showing the limestone and marlstone of Fatha Formation.

2.2 Physical – Mechanical tests

The ASTM and BS are used to determine the physical and mechanical characteristic of selected limestone and marlstone aggregates are summarized in Table 1. In general, aggregates should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities. Most of the sedimentary rocks are hard and durable and useful for aggregate. The quality of the limestone and marls resources and their ease and economy of working may be affected by a number of geotechnical factors. In order to investigate the possibility of using limestone and marlstone as coarse aggregate in construction materials, it was first necessary to investigate the physicomechanical properties. Limestone and marlstone aggregate samples were divided into five groups according to the locations of the deposits. The primary objective while collecting a sample for laboratory analysis is that its composition should be representative of the conditions that exist in the field. A total of 15 aggregate samples for each type were collected from 5 locations (3 samples for each location) in Fatha Formation in Koya area.

Table 1 – Physical and mechanical tests of samples accordance with ASTM and BS.

Test	Standard Method
Moisture content	ASTM C566 - 19
Water absorption	ASTM C127 - 15
Dry density	ASTM C127 - 15
Porosity	ASTM C29 / C29M - 17a
Los Angeles Abrasion Value (LAAV)	ASTM C535 - 16
Uniaxial Compressive Strength (UCS)	ASTM D5731-16
Aggregate Impact Value (AIV)	BS 812-112:1990
Aggregate Crushing Value (ACV)	BS 812-110:1990

2.3 Chemical composition of samples aggregates

To measure the X-ray intensity on the various elements a pellet was prepared for each sample of the crushed limestone and marlstone and analysed by X-ray fluorescence (XRF), as shown in (Table 2).

Table 2 – Chemical examinations of limestone and marlstone samples.

Rock Type	Oxides %								
	Location No.	CaO	SiO_2	$A1_20_3$	Fe_20_3	MgO	Na_2O	K_2O	SO_3
Limestone	1	58.7	28.2	7.46	1.82	1.31	0.45	1.88	0.23
	2	51.4	33.3	8.50	2.10	2.40	0.52	1.55	0.25
	3	43.5	38.7	10.30	2.50	3.50	-	1.29	0.26
	4	51.2	33.4	8.75	2.14	2.40	0.32	1.57	0.24
	5	52.3	35.2	8.46	2.03	2.28	0.50	1.61	0.21
Marlstone	1	62.2	23.3	6.37	2.49	1.05	-	1.67	2.94
	2	65.4	23.0	5.15	2.50	1.20	0.62	1.30	0.84
	3	58.7	31.4	3.99	2.15	1.36	0.68	0.83	0.89
	4	58.8	27.1	6.68	3.03	1.36	0.63	1.43	0.78
	5	60.4	25.3	6.45	3.37	1.38	0.65	1.39	0.86

3 Results and Discussion

3.1 Analyses of physical and mechanical properties

Aggregate possesses variety of physicomechanical properties which determine their suitability as a construction material. Quality of an aggregate is directly related to the source rock properties [13]. The results obtained from the physical and mechanical analyses of the values of crushed limestones and marlstone are presented in Tables 3 and 4, respectively. The results of density showing that the mean value of dry density is 2.40and 2.42 g/cm^3 for limestone and marlstone respectively, this indicate that limestone and marlstone have medium value of dry density (IQS, 1989) [14]. This range falls into the normal density category of aggregates (NF 1983) [15]. The dry density ranging between 2 - 3 g/cm^3 can also be considered medium weight aggregate, and the samples which have dry density 2.6 g/cm^3 are more suitable for aggregate [16]. The physical characteristics of rock aggregates are influenced by porosity and moisture content. The result of the average value of the moisture content is 0.98% and 1.15%, while the value of the absolute porosity is 5.38 % and 8.45% for limestone and marlstone respectively. According to the mean value of these rocks generally have very low moisture content and low porosity value for limestone and somewhat more value for marlstone than limestone. Aggregates may be susceptible to freeze–thaw damage depending on their pore structure and their absorption and permeability properties, however, the primary mechanism of freeze–thaw damage in aggregates relates to the freezing of water in the pores of aggregates under conditions of severe frost action [17]. Porous aggregates can help to reduce the disruptive expansion from alkali–aggregate reactivity [18]. The water absorption is a measure of the effective porosity of a stone. The total water absorption value indicates how much water a rock can absorb over 24 hours when placed (3–5) cm below the water level. The water uptake in relation to the dry weight of the sample is mainly influenced by porosity, pore size distribution and the mineralogical composition of the rock. It is dependent on the clay minerals present in the rock material which indirectly affects the strength [19]. The average of water absorption value (WAV) is 2.24% and 3.7% for limestone and marlstone respectively. The (WAV) of limestone is less than 3% indicating very low effective porosity of clasts (BSI 1987) [20]. If the (WAV) is low and less than the standard 3%, approved that the rocks samples are competent against frosting and chemical decomposition [21]. While the (WAV) of marlstone higher than 3% should be treated as suspect and checked for their influence on concrete performance [22]. On the other hand, (UCS) tests are the most commonly used geotechnical tests, and rock materials are generally classified based on their strength [23, 24]. The (UCS) of construction material is probably the most important index properties for the evaluation of mechanical behavior of rocks, because it provides a clear perception regarding the selection of material for appropriate civil structure [25]. The strength of rock decreases in the presence of joints and veins [26]. In the current study, the average value of (UCS) of the limestone and marlstone is 127.86 MPa and 32.5 MPa respectively. According to the proposed strength classification of NZGS [27], the value of the limestone pointed out that, this sample has very strong and inversely proportional with the lower water absorption [28]. Whereas, the (UCS) of marlstone is moderately strong. As a result, all these physicomechanical properties pointed out that the studied rocks samples are suitable for building industry and it is very necessary to invest these layers of rocks as raw material for the engineering construction.

Table 3 – Physical and mechanical characteristics of limestone samples.

Location No.	Moisture Content (%)	Dry Density (g/cm^3)	Water Absorption (%)	Porosity (%)	UCS (MPa)	LAAV (%)	AIV (%)	ACV (%)
1	1.29	2.32	3.1	7.14	68.18	30.86	13.80	23.25
2	1.04	2.33	2.9	6.90	99.6	30.77	12.01	22.76
3	0.95	2.40	1.9	4.71	114.8	29.37	11.50	22.50
4	0.86	2.45	1.8	4.43	133.7	27.94	11.37	22.28
5	0.75	2.50	1.5	3.74	223.0	26.50	10.73	21.96

Table 4 – Physical and mechanical characteristics of marlstone samples.

Location No.	Moisture Content (%)	Dry Density (g/cm^3)	Water Absorption (%)	Porosity (%)	UCS (MPa)
1	1.64	2.32	4.4	10.6	21.6
2	1.54	2.37	3.9	9.48	24.8
3	1.48	2.41	3.8	8.78	27.9
4	0.65	2.48	.34	7.29	31.05
5	0.46	2.53	.30	6.12	57.15

3.2 Analysis of aggregate degradation of limestone

High void percentage in carbonates increases Los Angeles abrasion. But, low voids decreases abrasion loss. On the other hand, carbonate freeze-thaw values are directly related to Los Angeles abrasion and inversely to degradation resistance [29]. The results obtained from the limestone aggregate determination tests, including the LAAV, ACV and AIV indicate that the average value of LAA is 29.1%. This value falls within the specification of 30% of NS (1994) [30] for coarse concrete aggregate showing that the studied crushed limestone have <30%, Therefore, lower AAV indicate limestone aggregate that is tougher and more resistant to abrasion, according to (ASTM C535, 2016) [31], it's commonly used in wearing surface, road and pavement construction. The abrasion resistance of materials such as limestone can significantly affect the service life of road pavements when exposed to long-term dynamic traffic loads. While the average value of ACV is 22.5%, show that the crushed limestone have value <25%, which means that are strong enough to resist fracturing under an applied compressive load. Therefore, lower ACV indicate that limestone aggregate is lower crushed fraction under load and would give a longer service life, higher quality, more economical performance and strong enough to withstand crushing under roller and traffic according to (BS: 812-110: 1990) [32]. So it's commonly used in wearing surfaces like runways and roadways, cement concrete pavement construction. Whereas the average value of AIV is 11.9 %, this value lies in the range of BS: 882: 1992; BS: 812-112:1990) [33, 34], where strong aggregates possess AIV between (10-20%). Therefore, lower AIV indicate that the studied limestone aggregate is strong and due to the recommended by committee of road construction (IRC), it's commonly used in the different types of road construction (flexible pavements, rigid pavements), heavy duty concrete floor finishes, wearing surface. On the other hand, it has been noticed that no study was done to use marlstone as aggregate in heavy building industry, because it's in natural state cannot be utilized as a construction material as many highway pavement failures have been observed. Due to their water sensitivity and low to moderate strength, there have been attempts to improve by stabilize the engineering properties using additives corrective materials such as lime, silica, aluminum.

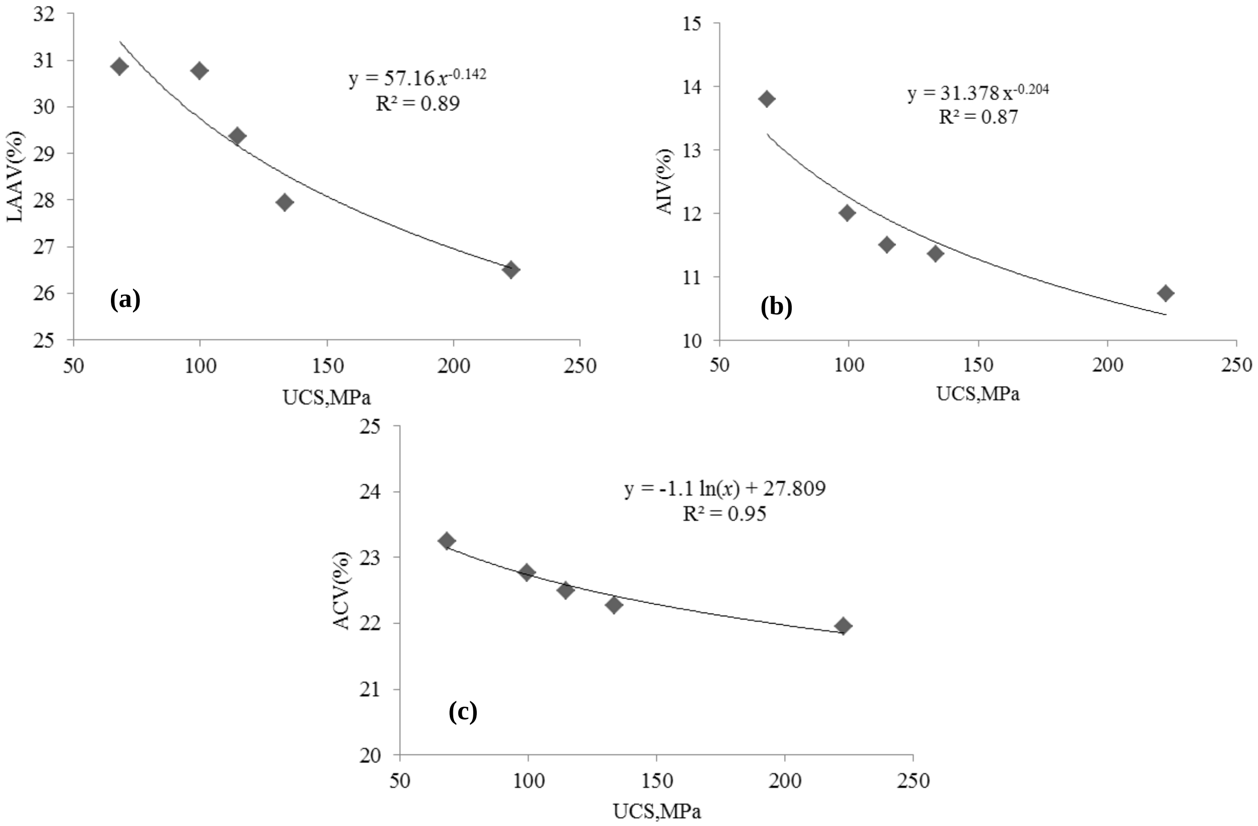

Fig. 3 – Relationships between UCS and AD tests: (a) LAAV, (b) AIV, and (c) ACV.

Marlstone is a swelling that gives a significant increase in bulk volume when water is present, as it gives high shrinkage ratio on drying. Swelling is dependent on the dry unit weight and increasing clay containing active clay minerals, such as; montmorillonite [8]. [35] Also indicated that the values of aggregate water absorption can be related to the type of clay mineral present and the feldspar and mica minerals. [36, 37] suggested that rocks with water absorption values greater than 3% have the potential to be damaged in freezing and thawing service conditions. While samples with water absorptions >4% need to undergo further tests to assess their quality in order to be used safely [38].

According to the marlstone aggregate determination test by (LAA), results obtained from this study shows that, it is impossible to use in heavy construction materials such as concrete or road pavement but may be it is usually used as sub-base layers for highway pavements, and non-structural concrete applications. This is proved by marlstone may be contain active clay minerals such as (montmorillonite, chlorite, illite), which they lead to cause somewhat shrinkage- swelling ratio, moderate strength and significant increase in bulk volume of marlstone when water and clay mineral are present.

3.3 Regression analysis

The present study deals with and discusses the results of a series of tests on these limestones and marlstone to evaluate their potential as a construction material. Mutual relationships of parameters have been described by simple regression analysis. The physicomechanical characteristics of these rocks were compared to acceptable limits of national and international standards for their suitability as aggregate sources.

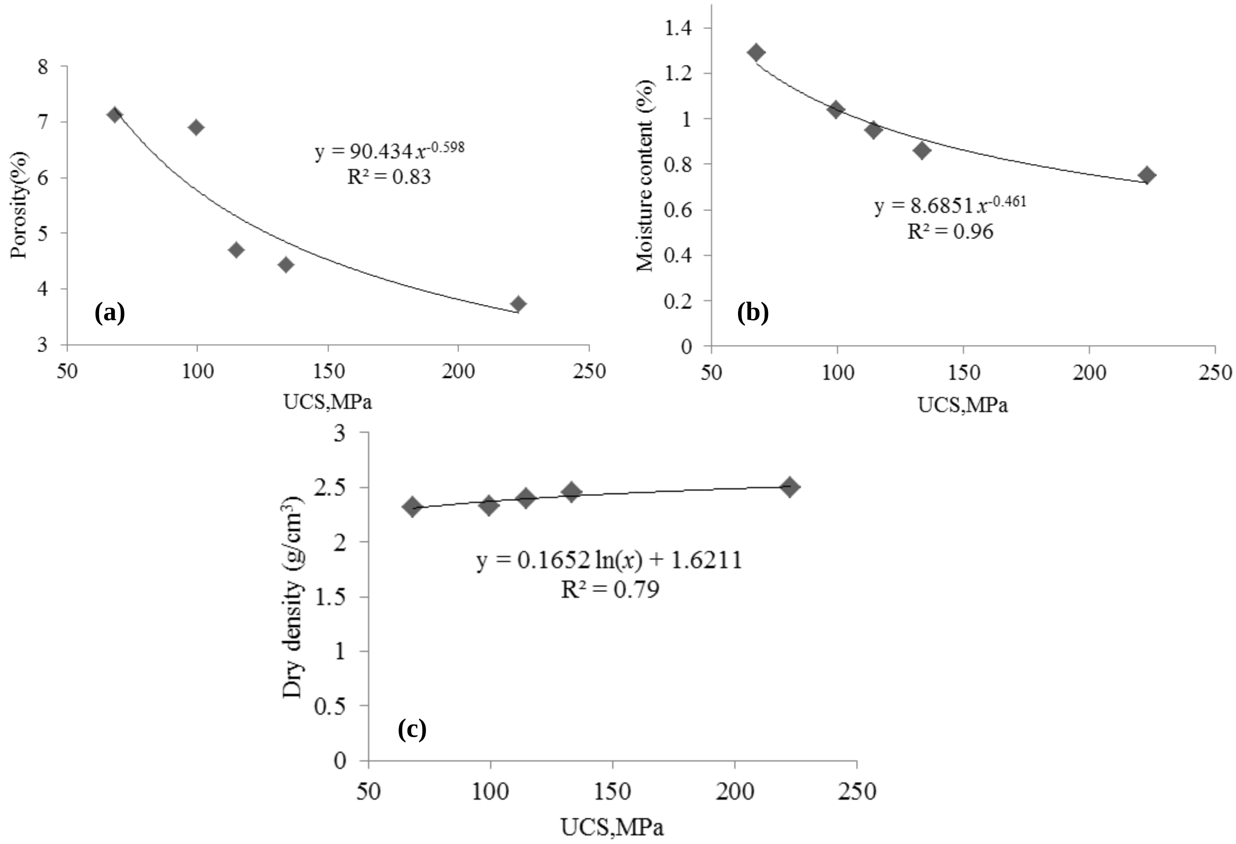

Fig. 4 – Relationships between UCS and physical properties of limestone: (a) porosity, (b) moisture content, and (c) dry density.

3.3.1 Relationship between UCS and AD tests of limestone

UCS values for all rock samples, regardless of location, categorize those as strong from an engineering viewpoint, according to the Geological Society and the IAEG International Association of Engineering Geologists [39, 40]. The aggregate degradation (AD) properties were evaluated by Los Angeles abrasion value (LAAV), aggregate impact value (AIV) and aggregate crushing value (ACV). Between UCS and AD tests of limestone samples, a nonlinear regression analysis was performed; it was presented in Fig. 3. Generally speaking, as UCS increases, it increases the resistance to aggregate degradation. Fig. 3c shows that a strong logarithmic relationship with (0.95 R^2) existed between the UCS and ACV. A similar trend has been reported that is a higher R^2 between UCS and ACV by Kamani and Ajalloeian. They found that UCS and ACV getting the same loading scenario because rock sample or rock aggregate is broken under a gradually applied compressive load, a case that may happen in highway subgrades, railroad ballast, rockfills, and aggregates used in foundations or as tunnel backfills [41].

3.3.2 Relationship between UCS and physical properties of limestone and marlstone

Several researchers have correlated the physical and mechanical properties of rocks used as aggregates [42-44]. The inverse relationship between UCS and porosity and moisture content for limestone was shown in Figures 4a, and 4b. As well as the same behavior as shown in figures (5a, 5b) for marlstone samples also. Figure 4b suggests a strong correction between

UCS and water content in a power relationship with (R2=0.96) for limestone. On the other hand, a good correlation with (R2 =0.81) for marlstone. The figures (4d, 5d) show a proportional relationship between the density and the UCS, with a good correlation (R2 = 0.79, R2=0.85) for marlstone and limestone respectively.

The results indicate that there is a strong significant correlation between the parameters of limestone and marlstone to use as construction materials. According to the results of UCS, marlstone has moderate strength can be used for road construction as subbase course and non-structural concrete applications.

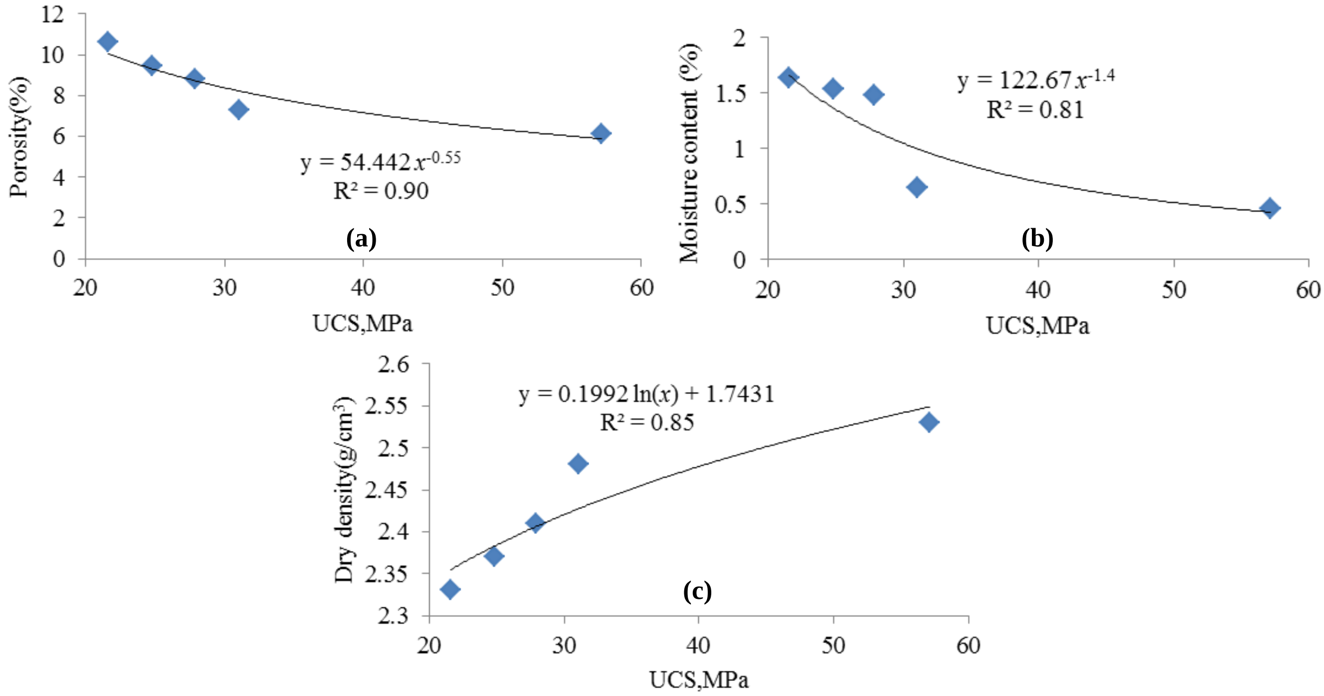

Fig.5 – Relationships between UCS and physical properties of marlstone: (a) porosity, (b) moisture content, and (c) dry density.

4 Conclusion

The surrounding area around Haibat Sultan Mountain contains large quantities of rocks that can be used as a construction material in the manufacture of concrete or road works. The comprehensive characterization of physical and mechanical properties pointed out that crushed limestone has strong and marlstone has moderately strong compressive strength. All of the tested samples had a medium-dry density with medium moisture content and porosity. These results indicate that the rocks are slightly weathered and more durable. All of these tests play a very significant role in rock engineering construction projects.

According to aggregate degradation tests, all the values of (LAAV, ACV, AIV) are within safe limits for most construction work. According to the results of the aggregate type’s tests, the studied crushed limestone samples showed the highest resistance to abrasion, crushing, and impact (toughness) and are acceptable for base course in road construction and as aggregate in concrete mixes. Whereas, the studied crushed marlstone samples showed the moderate strength and are acceptable for subbase course in road construction and non-structural concrete applications.

The low thickness of the overburden with weak hardness has significant economic benefits making the reserve mine ability very easy and then eventually reducing the final cost of crushed limestone and marlstone aggregates.

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